JPL SP 43-10, VOL. 2

Space Science Board Summer Study 1974

Planetary Mission Summary: Mars Polar Orbiter

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103

August, 1974

(NASA-CR-147094) PLANETARY MISSION SUMMARY. VOLUME 2: MARS POLAR ORBITER (Jet Propulsion Lab.) 14 p HC $3.50 CSCL 03B
N76-23130
Unclas
G3/91 27537

National Aeronautics and Space Administration

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Foreword

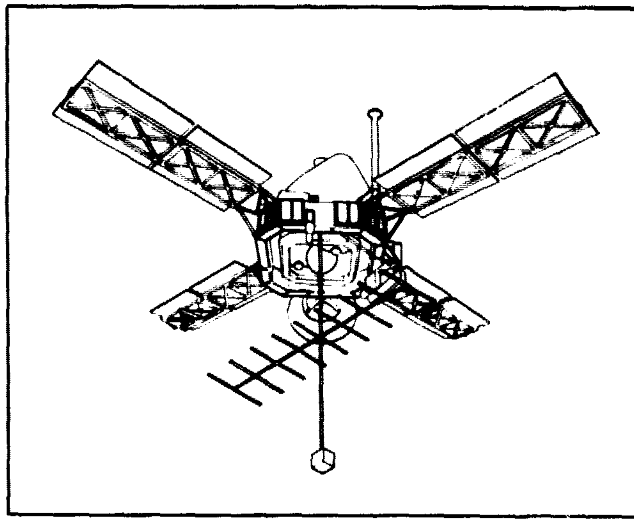
This volume presents one of a collection of planetary mission definitions which summarize what is now known about several future missions of current interest in NASA planning. Since the missions are at various stages in the planning process, the firmness and validity of the information vary. The level of detail presented, however, is uniformly concise and reflects our present best estimate of the likely characteristics of each mission. Most of the information comes from JPL technical studies sponsored by NASA.

For this mission, the choice of baseline reflects our initial judgment as to what level of performance gives a viable combination of scientific potential, development schedule, and cost. Variations from the baseline, such as launching in a later year or using a smaller or larger spacecraft, are included where they have been studied. Our objective has been to compile in brief form the main technical conclusions of recent mission studies in order that these results may interact with the broader questions of scope, pace, and priorities in the planetary exploration program as a whole.

W. H. Pickering
Director, Jet Propulsion Laboratory

Mars Polar Orbiter

Launch Date: November 1979
Orbit Insertion: September 1980
Orbital Lifetime: 1 Martian year
Injected Mass: 2388 kg
Orbited Mass: 982 kg
Instrument Mass: 100 kg
Launch Vehicle: Titan III-E/Centaur, one launch



Objectives:

To survey geochemistry of Mars. To map elevation and roughness of surface. To make detailed geological studies. To make climatological investigations including determination of polar glacier composition and dust-storm mechanisms. Gravitational field determination. Reconnaissance of sites for future landings.

Typical Science Investigations:

Gamma-ray spectrometer
Radar altimeter/sounder
High-resolution imaging system
Infrared sounder/water vapor detector
Synoptic imaging system
S- and X-band occultations
Gravity field (radio tracking)

Mission Description:

A single Viking Orbiter spacecraft (VO75 PTO hardware with minor modifications) is injected into a circular polar orbit about Mars after a Type II transfer from Earth. The altitude is 1000 km, inclination 95 deg; the orbit is Sun-synchronous. Operations are programmed in a simplified, standard mode to minimize cost. X-band telemetry is used to increase data return. A two-year orbital mission is planned.

Status:

Preliminary mission design studies currently underway. Polar orbiter mission also feasible for 1981 Mars opportunity.

Estimated Funding:

(1) Launch vehicle and DSN-support funding excluded.

(2) Assumes Viking Orbiter 1975 PTO hardware available; $9–12 million (FY75 dollars) required for new Viking hardware build, if necessary.

(3) Inflated dollars equal 5% annual inflation.

Fiscal year	77	78	79	80	81	82	83	Total
FY75 dollars (millions)	2.4	23.0	52.6	21.5	22.8	8.0	3.3	133.6
Inflated dollars (millions)	2.7	26.6	63.9	27.4	30.6	11.3	4.9	167.4

Mars Polar Orbiter

I. Science

A. Rationale

A low-cost option for a 1979 mission to Mars is that of flying the Viking Orbiter PTO spacecraft with a largely new science payload. Unburdened by a lander, the spacecraft could place a substantial payload into a high-inclination, 1000-km-altitude, circular Sun-synchronous orbit that would be ideal for geoscience and for meteorological measurements. In contrast to the highly elliptical orbits generally accessible, this orbit would make all latitudes equally well observable with high resolution. The spacecraft, if equipped with X-band telemetry, would provide as powerful an orbital science capability at Mars as can presently be visualized.

The polar orbiter mission discussed here is envisioned to operate for one Mars year and to return large quantities of data. Mission operations would be greatly simplified by comparison to previous Mariner and Viking missions. The mission would be designed to capitalize on and consolidate the Mariner 9 discoveries and to complement and exploit the results of the Viking landings in 1976. The geoscience return from the mission could include such fundamental data as a global survey of surface chemistry, an accurate measure of the figure of the planet, and an improved and complete measurement of the gravity field. The spacecraft could perform a global reconnaissance for the radioactive elements uranium, thorium and potassium 40, in addition to many other geochemically important elements. It could also observe global variations in the state of oxidation of iron. By means of radar it could probe the subsurface and collect data pertaining to terrain roughness down to scales of 1 meter and less, which are inaccessible with current television imaging technology. Imaging experiments could also be conducted for both geological and dynamical studies, and an infrared instrument could be used for meteorological investigations. The information gathered by this polar orbiter would greatly extend our knowledge of Mars and would be crucial in selecting safe and scientifically important sites for future lander missions. The mission would serve as a highly desirable precursor for a later mission to recover a soil sample from the Martian surface.

Analysis of the Mariner 9 data has shown that Mars is a geologically exciting planet and has led to various speculations about Martian evolution. In this regard, Mariner 9 has provided evidence, with the discovery of layered sedimentary terrain in the polar regions, that the climate of Mars has undergone periodic variations. It has been argued that such climate changes could be the result of cyclic variations in the Martian orbital elements. Channels, apparently of fluvial origin, have also been discovered. These may date back to the early history of Mars or may be related to catastrophic climate change occurring when large quantities of volatiles, hypothesized to be condensed in polar glaciers, are released (as a result of an increase in Martian obliquity or due to a change in solar luminosity) back into the atmosphere. The question of whether large quantities of volatiles are indeed stored at the poles is important to answer in relation to the climate change problem, and, more generally, in order to assess the extent of outgassing from the interior. For a similar reason, since the regolith is expected to be a major reservoir of adsorbed and chemically bound volatiles, information about the depth of the Martian regolith is very important to acquire.

B. Objectives

The exploration of Mars aims at discovering the manner in which the planet has evolved, to which end the following information is needed:

(1) The chemical composition of the planet.

(2) The thermal history of the planet.

(3) The degree of differentiation that has been achieved.

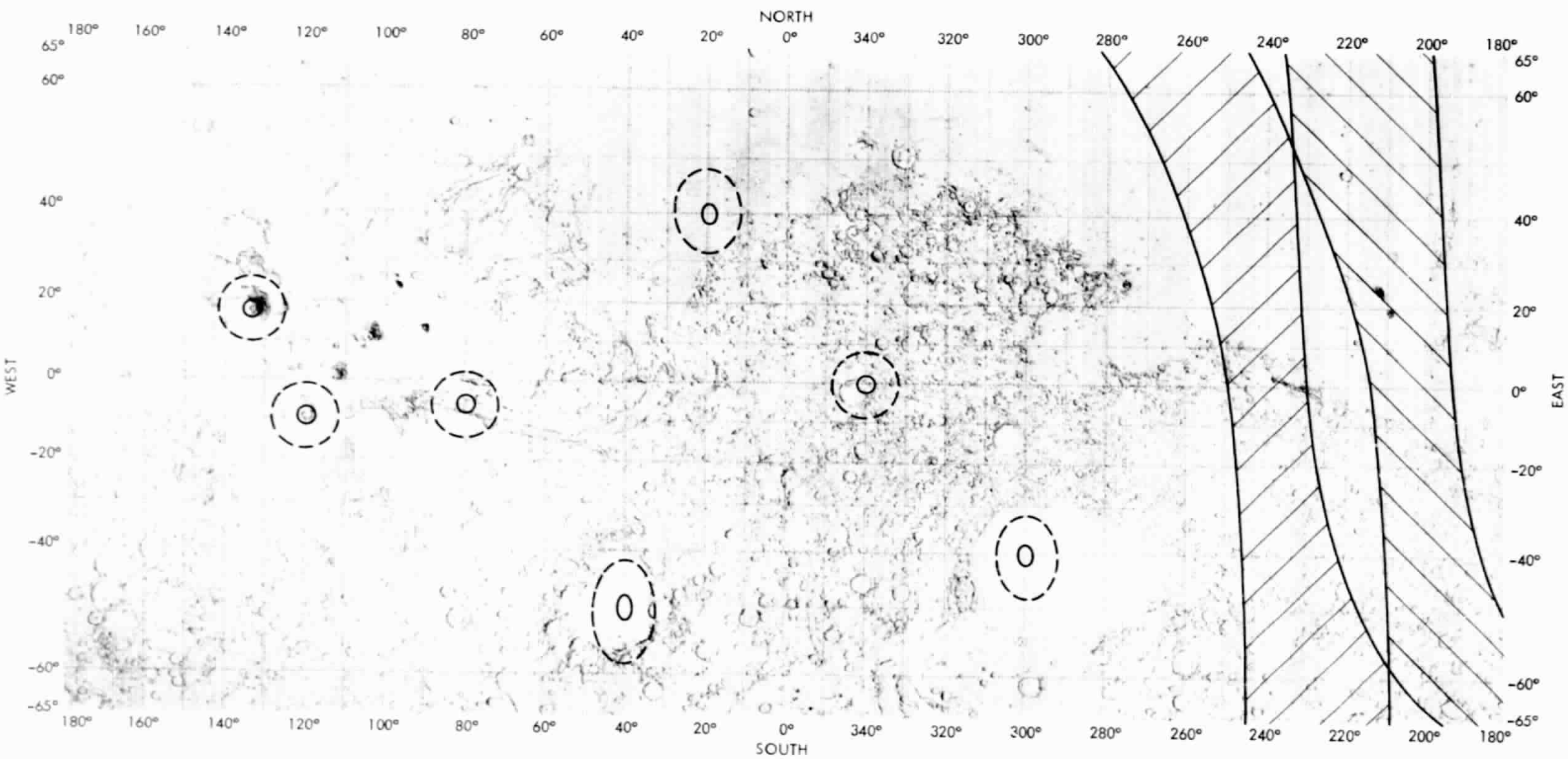


Fig. 1. Resolution of gamma-ray spectrometer (solid) and gravity (dashed) experiments. Shown at right is coverage obtained on two successive revolutions by synoptic imaging experiment (10 revolutions daily)

(4) The internal density distribution.

(5) The history of the surface and atmosphere.

The proposed Mars Polar Orbiter is intended to acquire data of a variety of kinds to allow significant advances to be made towards achieving this goal. Four complementary and interrelated types of investigation could be advantageously undertaken by the orbiter—a geochemistry survey, a measurement of the complete gravity field and of the figure of the planet, a detailed investigation of Martian geology, and a study of Martian climatology.

The geochemistry survey would be made with a collimated gamma-ray spectrometer having a spatial resolution of about 200 km (Fig. 1). The result would be a determination of the distribution and abundance of natural and induced (by cosmic rays) radioactive nuclei in the top half-meter of the surface. The data would not, however, be restricted in significance to the immediate surface of Mars, because the abundances of certain elements are diagnostic of the overall composition of the planet even when the planet is differentiated. The measurement of the ratio of potassium to uranium is of particular importance since it provides information about the relative abundance of volatile and refractory elements —key data for studying the thermal history of Mars.

The abundances of natural radioactive nuclei are strongly influenced by the extent of differentiation of the planet, and the measurement of these abundances—both planet-wide and also regional variations—will be of major importance in reconstructing the evolution of Mars. Such measurements should allow, for example, a much better understanding to be reached of the north-south asymmetry of Mars—a characteristic which may be analogous to terrestrial continental and oceanic crust differences.

Measurements of induced radioactivity will provide important information about the distribution of different rock types and about the presence of volatiles, including the composition of the surface of the polar glaciers. Such measurements are of vital importance for geological and climatological studies and will complement that acquired by the Viking inorganic chemistry experiment and by the Viking gas chromatograph/mass spectrometer.

Measurements of the figure and gravity field of Mars provide an approach to the study of Martian evolution that is complementary to the chemistry survey. The gravity field of the planet depends upon the structure of both the crust and the interior of the planet, both of which are a reflection of the chemistry and thermal history of Mars. By observing the gravity field and by using information about the shape and surface chemistry of Mars, it is possible to learn about thickness variations of the crust and, as a next step, to learn more about the internal density distribution. Studies of this kind have been made with the Mariner 9 data, but the incompleteness of the gravity data and the relative crudeness of the topographic data limit the analysis that can be made. Radar altimetry from a polar orbiter could measure the planetary figure to great precision. The gravity data from the proposed orbiter may prove to have sufficient resolution (about 1000 km, Fig. 1) to determine the degree of compensation associated with specific topographic features such as Mons Olympus and Vallis Marineris. In the first case, the gravity data could yield information about the depth of compensation and, perhaps, about the likely depth of the magma source. The detection of gravitational anomalies associated with the vast equatorial canyon could provide important clues about the origin of this feature.

Where geology studies are concerned, the overwhelming success of the Mariner 9 imaging experiment has tended to obscure the limitations of the data that were acquired. For significant advances to be made in many areas opened up by the analysis of Mariner data—volcanology, global-regional tectonics, erosional processes, channel formation, etc.—a body of much improved data, including additional high-resolution imaging, is required. The proposed orbiter mission, by combining the acquisition of substantial amounts of high-resolution imaging data with radar elevation and roughness data and with global geochemistry data, will enable current Martian geological studies to be greatly refined and extended.

To make progress in studies of Martian climatology the answers to the following questions are needed:

(1) Is the atmosphere "buffered" by solid CO_2 reservoirs?

(2) What is the composition of the polar glaciers—H_2O, CO_2, or CO_2 buried beneath H_2O?

(3) How thick are the glaciers?

(4) Do the layers of the sedimentary polar terrains reflect periodicities in the frequency and intensity of dust storms?

(5) How much CO_2 and H_2O are adsorbed in the regolith?

(6) What are the mechanisms of atmosphere H_2O transport?

(7) How old are the fluvial channels?

(8) Has substantial liquid water weathering occurred on Mars?

(9) What is the erosional history of the ancient cratered terrain?

(10) What is the distribution of permafrost?

These questions, which span a range of disciplines, could prove tractable if the proposed polar orbiter were used to acquire the following types of information:

(1) Gamma-ray spectrometer data in the polar regions.

(2) Planetwide imaging data in the 1-μ absorption band of Fe^{++}.

(3) IR radiometric data on the polar glaciers during summer.

(4) High-resolution imaging data of the glaciers and cratered terrain.

(5) Radar sounding of the glaciers, layered terrain, and regolith.

(6) Repeated imaging of the seasonal polar cap behavior.

(7) Temperature/pressure profiles of the atmosphere for meterological studies leading to an evaluation of the factors that account for the high winds of southern summer.

(8) Imaging data of the growth of large-scale dust storms.

(9) Radio occultation measurements of seasonal atmospheric pressure changes.

(10) Variations of atmospheric abundance of water vapor.

While acquiring the various data needed for the climatology investigation, progress would also be made toward answering many important questions in the areas of Martian meteorology and surface/atmosphere interaction. These include such inadequately understood matters as the effect of topography on local and global circulation, the effect of the atmosphere on the rate of growth and retreat of the polar caps, and the mechanisms of erosion and deposition of surface material. There are also unusual features to the atmospheric circulation over the retreating polar cap that call for further detailed investigation. On a planet like Mars, where surface/atmosphere interactions have significantly shaped the appearance of the surface, it is very important that such dynamics studies not be neglected.

All of the information gathered by an advanced orbiter of the type proposed would be important in assessing the most interesting sites for later lander missions, with high-resolution imaging and surface chemistry data assuming the greatest importance. The key data for determining the safety of potential landing sites would be the radar data on elevations, roughness and dielectric constant, together with the high-resolution imaging data and the meteorology results. With such data in hand, future landing missions (including sample return) could be flown with a bare minimum of site certification activity. Thus any orbiters associated with such missions might reasonably be designed simply as relay links rather than as highly constrained science data gatherers.

C. Typical Payload

The payload that has been considered for the mission has generally been selected from instruments that have already been flown or could be derived from such instruments. The exception is the synoptic imaging system which is judged to be an integral part of the proposed payload and which should be straightforward to develop. It should be noted that new instruments of interest for Martian studies may be developed for a forthcoming Lunar Polar Orbiter. Such instruments may allow the mission objectives to be extended and for the science return to be significantly enhanced.

To achieve the objectives outlined above, the orbiter would need to include in its payload a gamma-ray spectrometer, radar sounder/altimeter, high-resolution imaging system, synoptic imaging system, and IR atmospheric sounder. The radio subsystem would also be considered part of the payload for occultation and gravity field studies. The Viking Orbiter has a payload and power capability in excess of that described and could accommodate additional experiments to meet further objectives, e.g., particle and fields experiments and spectroscopic determinations of surface miner logy.

1. Gamma-ray spectrometer. The spectrometer measures the flux of gamma rays from natural radioactive isotopes and also from those produced by the interaction of surface matter with incident cosmic rays. A germanium sensor of high purity would provide very much improved sensitivity in comparison to previously flown NaI(Tl) sensors. Information will be acquired about the abundance of these elements—U, Th, K, Fe, Mg, Si, O, H, C, Ti, Al and Ca—permitting inferences to be made about the near-surface presence and distribution of volatiles and about the accretionary and differentiation processes that have occurred in the evolution of Mars.

Summary of characteristics
(1) Germanium sensor, passively cooled.
(2) 0.5 – 10 MeV energy range.
(3) 2-keV resolution.
(4) collimator (active).
(5) ~200-km-diameter resolution segment, boom-mounted, rotatable.
(6) 1 kbps.
(7) 10 W, 17 kg.

2. Radar sounder/altimeter. The radar sounder/altimeter experiment has several objectives—to accurately and completely measure the shape of the planet, to provide roughness data at meter scales, to acquire dielectric constant data, and to probe the subsurface down to 100 m in specific regions. The topographic elevation data is of key importance for geophysical and geological studies, while the roughness/dielectric constant information has particular importance for landing site selection as well as for geological purposes.

It is judged that the radar sounding data are likely to yield appreciably more significant results for Mars than those that have thus far been forthcoming from the lunar data analysis. Specific objectives are:

(1) To search for discontinuities in the polar glaciers.

(2) To measure the thickness of the glaciers.

(3) To study layering in the smooth laminated terrains.

(4) To measure the thickness of ice in polar "outliers."

(5) To study characteristics of the regolith.

The sounder data also can be used to provide radar images and thus will allow the topography of Hellas to be observed in the postulated presence of a permanent dust pall.

The radar sounder experiment is considered to be particularly well suited to this mission because of the importance of polar studies and because the Viking spacecraft is alone in its capability for supplying the data acquisition rate and power needed for the experiment.

Summary of characteristics
(1) 2-m wavelength.
(2) 4-m-long Yagi antenna, boom mounted and rotatable.
(3) 10-m vertical resolution.
(4) 50-m horizontal resolution in sounder mode, 1500 m in profiler mode.
(5) 100-m penetration depth.
(6) 1 Mbps data (recorded) in sounder mode, 1 kbps in profiler mode.
(7) 18 kg, 100 W.

3. High-resolution imaging system. The high-resolution imaging system would be unchanged from that of Viking Orbiter 1975. All data would be recorded along the ground track during a 7-minute period and played back at ~100 kbps during the remainder of the revolution. The length of a single swath would be ~1000 km, the width ~50 km. Contiguous swaths would be achieved by virtue of the slightly nonsynchronous orbital period. The data would be used primarily for geological studies including characterization of the polar glaciers and layered terrains.

Summary of characteristics
(1) Two 475-mm focal length vidicon cameras.
(2) ~80-m/line pair surface resolution.
(3) All data recorded at 2 Mbps.
(4) Scan-platform-mounted.
(5) 50 kg, 45 W.; same as Viking system.

4. IR sounder/radiometer/water vapor detector. The IR sounder would operate in conjunction with the synoptic imaging system (discussed below) to characterize the meteorology and dynamics of the planet. Temperature/pressure profiles, acquired from pole to pole at 10 longitudes daily, would provide the essential data for detailed circulation studies. Particular attention would be paid to determining the conditions that lead to global dust storms and to identifying the effects of topography on circulation. The meteorology of the polar region, including the effects of the atmosphere on seasonal polar cap behavior, would also be investigated. The water vapor channel would allow the processes that lead to marked variations in water vapor abundance to be studied. The inclusion of the surface temperature channel is

intended principally to ensure that measurements can be made of the summer polar glaciers in the event that the second Viking Orbiter 1975 does not acquire this data (that orbiter will initially be inserted into an orbit that cannot observe the poles). This temperature data would provide a means of distinguishing between water and CO_2 glaciers.

Summary of characteristics

(1) Nine radiometer channels: 7 for profile (2.1 to 0.0009 mb), 1 for surface temperature, 1 for water vapor.

(2) Five interference filter channels.

(3) Four pressure-modulated cell channels.

(4) Profiles to 80 km altitude.

(5) Scan-platform-mounted.

(6) 1 kbps.

(7) [illegible] deg field of view.

(8) 7 kg, 4 W.

5. Synoptic imaging system. The wide-angle camera would acquire data for 600 km on either side of the ground track, thereby providing complete planetary coverage each day poleward of ~50 deg latitude. This data would be used to study the growth of dust storms, the weather systems within the polar hoods, the growth and retreat of the polar caps, surface albedo variations and the seasonal variation of tropical water ice clouds. A filter optimized for imaging in the 1-μm absorption band of Fe^{++} would be used to map the variation of Fe^{++} concentration across the planet for studies of weathering processes.

Summary of characteristics

(1) 1000-element line array (CCD).

(2) 70 deg field of view.

(3) 2-km/line pair resolution.

(4) No shutter.

(5) Three fixed wideband filters.

(6) Photometrically accurate.

(7) Scan-platform-mounted.

(8) 20 kbps.

(9) 2 kg, 10 W.

6. Radio. Radio occultations occurring within the last half of the mission would provide data on seasonal pressure changes and on the figure of the planet. X-band and S-band tracking of the spacecraft would allow the gravity field of the planet to be determined with a ~1000-km-diameter resolution element.

II. Mission Description

The orbiter would be launched on a Titan III-E/Centaur booster in November 1979 with MOI occurring in September 1980. End of mission would be in August 1982. The general calendar of events, including Mars seasonal characteristics, is shown in Fig. 2.

After MOI a minimum of two trims would be needed to achieve the desired orbit, whose characteristics are:

Period:	2.467 hr
Inclination:	95. deg
Altitude:	1013 km
Eccentricity:	0

The orbit (Fig. 3) would be oriented such that the angle between the orbit plane and that of the terminator is about 30 deg. In this circumstance there are no solar occultations. Earth occultations, which last up to 50 minutes, occur in the last half of the mission.

The period is about one-tenth of the Mars rotation period so that adjacent ground tracks, which move progressively westwards, are separated by about 36 deg. To allow mapping of all parts of the planet with contiguous swaths of high-resolution images the period is selected to move the ground track by about 0.7 deg longitude each day. A very simple science operation is visualized with minimum adaptivity—important factors in reducing the cost of the mission and the need for major scientist participation in mission operations. Simplicity is achieved by ensuring the return of a large amount of data with essentially complete planetary coverage each day by the IR sounder and wide-angle cameras. Thus nearly all dynamical phenomena will be observed automatically. Decisions, which can be planned with ample lead-time, will have to be made as to where the high-resolution imaging and radar sounding will be acquired and which of these will be recorded on any particular revolution.

All of the data except the high resolution imaging and the radar sounding would be sent back directly in real-time at ~30 kbps using X-band telemetry. The recorded data would be sent back at ~120 kbps to the Goldstone antenna only—a cost saving measure to avoid the rental of high-speed data lines.

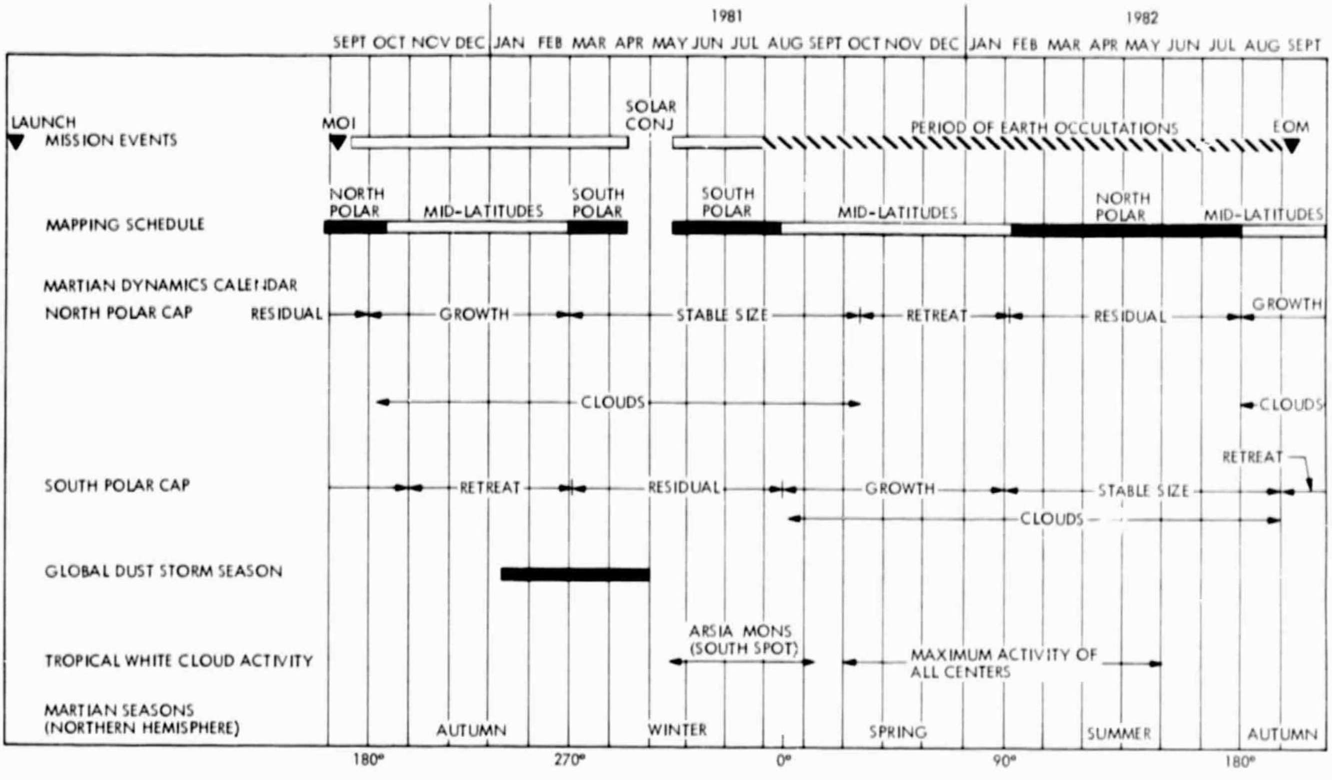


Fig. 2. Mission events calendar

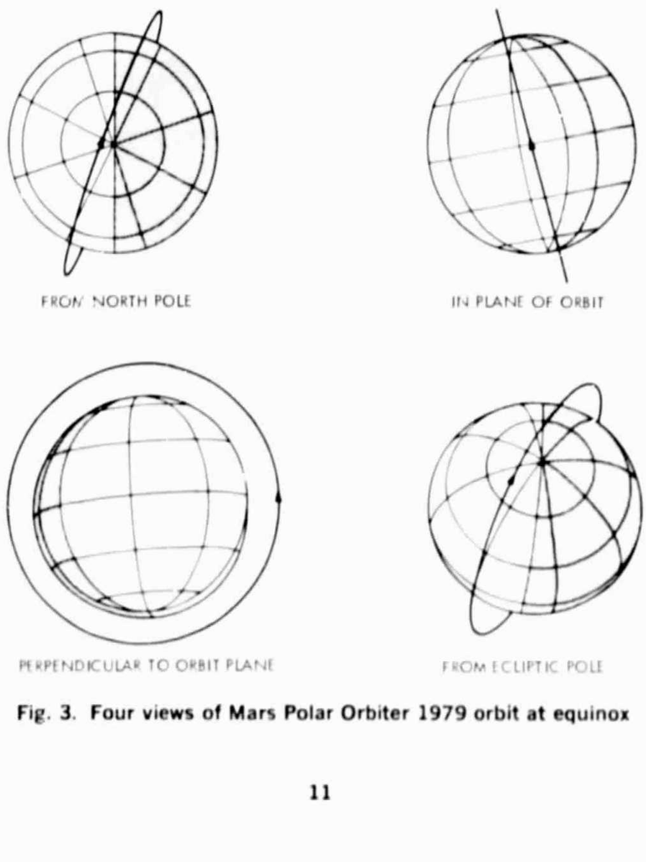


Fig. 3. Four views of Mars Polar Orbiter 1979 orbit at equinox

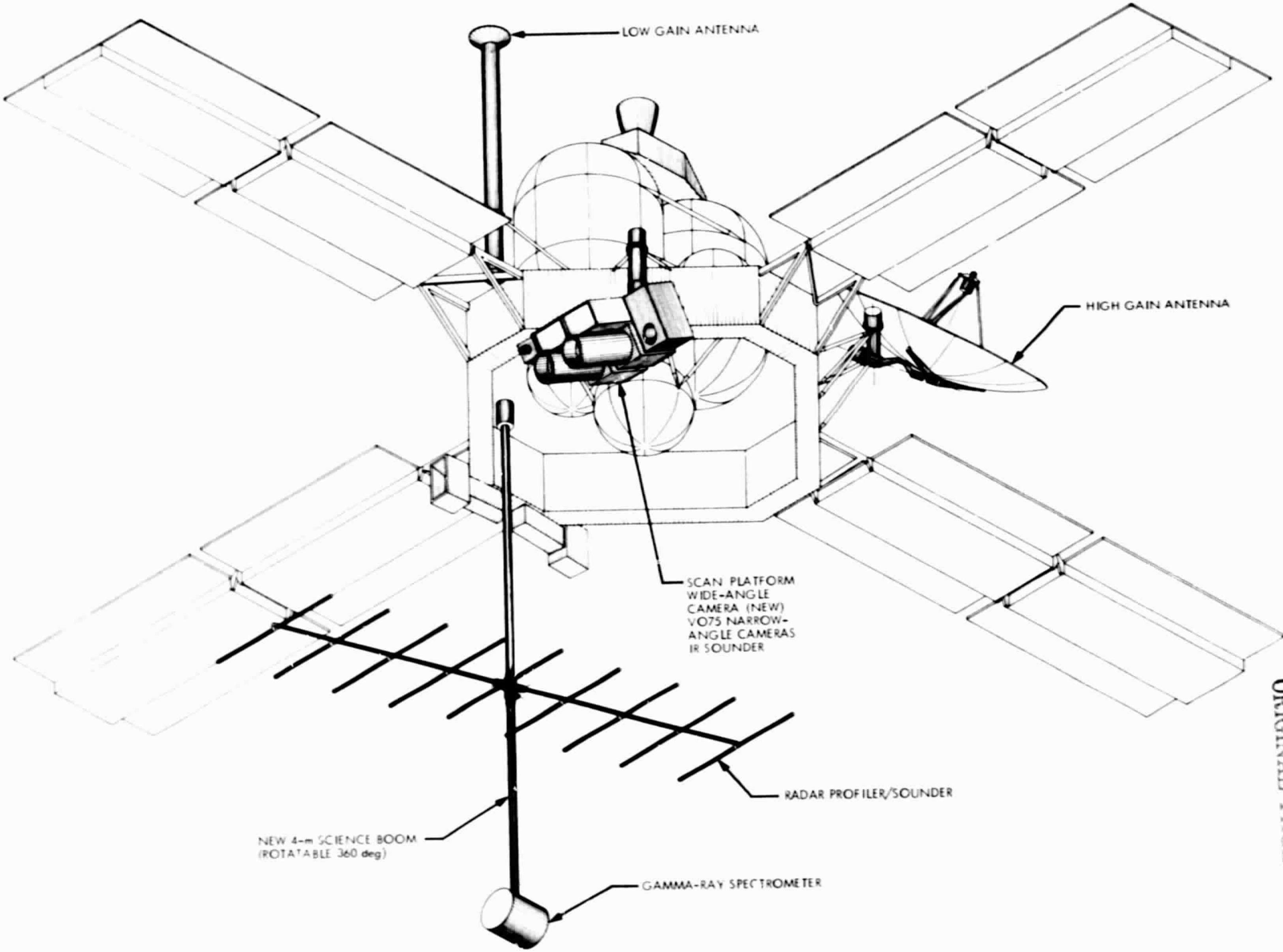


Fig. 4. Modified spacecraft configuration

III. General Spacecraft Characteristics

The spacecraft proposed for the 1979 polar orbiter mission is the PTO spacecraft from the Viking 1975 mission. This spacecraft is similar in many respects to Mariner-class spacecraft but has two attributes of special value for the proposed mission—a very large ΔV capability and a data storage system able to accept data at very high rates. The first attribute permits insertion into a low-altitude circular orbit, and the second permits (in addition to a capability for contiguous high-resolution imaging using the Viking cameras) a radar sounding experiment to be carried out. The very-high-power output of the solar panels is also valuable since the radar experiment is a large power consumer.

Various modifications to the spacecraft (Fig. 4) are required to permit the experiments described above to be carried out during a one-Mars-year orbital mission. These are:

(1) Extra attitude control gas (45 kg) in tanks external to the bus, replacing the internal tanks.

(2) X-band radio system to permit high-rate data to be played back at all Earth–Mars distances.

(3) Rotatable boom for gamma-ray spectrometer and radar antenna.

(4) Second star sensor on opposite side of bus from Canopus tracker to avoid use of gyros.

(5) Simultaneous playback of all seven tracks of tape recorder to minimize head and tape wear (significantly simplifies ground data reconstruction also).

IV. Mission Options

The basic Viking Orbiter spacecraft has a considerable payload weight and power capability and could carry a variety of science instruments other than those described above. One interesting option that has been tentatively examined is the possibility of adding penetrometer probes to the spacecraft. Such probes could be used for localized seismometry, chemistry, and surface characterization studies. The addition of several such probes would probably require that the propulsion tanks of the spacecraft be "stretched" if the sun-synchronous orbit were to be maintained. Such an orbit would be ideal for the launching of the probes since any point on the planet could be a target— in contrast to elliptical orbits where the target must be near the periapsis latitude. This might be a very important consideration if the penetrometer were powered by RTG's, since the gamma-ray experiment would be of limited use until all the probes had been released. Deployment of the probes from a three-axis stabilized spacecraft such as the Viking Orbiter is expected to be relatively simple.

To accommodate penetrometer probes, the boom-mounted gamma-ray spectrometer and radar antenna would have to be relocated. Insofar as the penetrometers would be used for subsurface studies, the radar sounder might be replaced by a simple altimeter. The parabolic antenna could then be scan-platform-mounted. The gamma-ray spectrometer could also be scan-platform-mounted at the expense of added weight to provide active shielding of the sensor.

A second option with the potentiality for significantly adding to the science return of the mission is the addition of a subsatellite for high-resolution studies of the gravitational field and of the planet's residual magnetic field (other experiments might also be carried). As in the case of the penetrometers, sterilization would be necessary. This option seems to present appreciably less technical risk than the penetrometer option and, arguably, to promise an equal science return. It has not, however, been possible to pursue this option in detail and no reliable cost figures are available.

Where launch year options are concerned, the polar orbiter mission described here could be flown at any programmatically advantageous opportunity. The 1981 opportunity does involve higher encounter velocities, and some spacecraft propulsion modifications might, therefore, prove necessary for that year.

V. Program Assessment

The cost study performed for the Mars Polar Orbiter Mission was based on the following assumptions.

(1) Launch vehicle and DSN-support costs excluded.

(2) Single flight spacecraft with selected spares (not assembled).

(3) Assumes Viking Orbiter 1975 PTO spacecraft available; \$9–12 million (FY75 dollars) required for new Viking hardware build, if necessary.

A breakdown of the estimated costs in millions of dollars (FY75) is as follows:

Science	27.1
Spacecraft	40.8
Mission operations	30.2
MCCC	7.6
Project management and integration	9.0
Contingency	18.9
Total	133.6

The funding spread is given in Table 1.

Table 1. Mission funding spread

Fiscal year	77	78	79	80	81	82	83	Total
Millions of dollars (FY75)	2.4	23.0	52.6	21.5	22.8	8.0	3.3	133.6

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